Multicolor photometry of the GRB970508 optical remnant

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We report results of follow-up multicolor photometry of the optical variable source that is a probable remnant of the gamma-ray burst GRB970508 discovered by the BeppoSAX satellite (IAUC 6649). Observations were carried out in Johnson-Kron-Cousins BVR_cI_c system with the 1-m and 6-m telescopes of SAO RAS. Between the 2nd and the 5th day after the burst a fading of the remnant is well fitted with an exponential law in all four bands. During this period the 'broadband spectrum' of the object was unchanged and can be approximated by a power-law, $\boxed{F_\nu \propto \nu^{-1.1}}$. After the 5th day the decline of brightness is slowed down. In the R_c band until the 32nd day, the light curve can be described by a power-law relation, $\boxed{F_t \propto t^{-1.2}}$.

THE SEARCH FOR AN OPTICAL COUNTERPART

The first coordinates of $10'$ radius error box for the GRB970508 (May 8.904 UT) were received in SAO RAS from the BeppoSAX team (by phone) on May 9.05 UT. At that time observations were not possible because of beginning of morning twilight. On May 9.3 UT the refined coordinates of $5'$ radius error box were received by e-mail from the BeppoSAX team.

The search for optical counterpart began with the 1-m telescope on May 9.74 UT. The 5' error box for the GRB970508 localization was completely covered with the CCD mosaic of 29 images in R_c band with 300 and 600 sec exposure times. The CCD photometer at the 1-m (Zeiss-1000) telescope is equipped with a ISD015A chip of 520×580 pixels corresponding to the field of view $2.0' \times 3.'6$. The images from the 1-m telescope were compared to the corresponding fields of the Digitized Sky Servey (DSS). No new bright object was found up to the DSS limit for this field.

On the next night, May 10/11 a better position was available: $\alpha_{2000} = 06^h53^m28^s$; $\delta_{2000} = +79^o17'.4$ with a $3'$ error radius (99% confidence level). Photometric observations of GRB970508 field were then continued with the 6-m telescope with a CCD photometer installed at the Primary Focus. The CCD chip "Electron ISD017A" was used; its format of 1040×1160 pixels corresponds to the field of view of $2.'38 \times 2.'66$. A 2×2 binning mode was employed, so that each of the 520×580 zoomed pixels (referred to as 'pixels' hereafter) has angular size of $0.''274 \times 0.''274$. The gain is $2.3e^-$ per

DN (Data Number). The readout noise is about 10e⁻.

The first image on the 6-m telescope was obtained on May 10.76 UT and a variable object was discovered using our data from the 1-m telescope. Its brightness from May 9.85 UT to May 10.76 UT increased about 1.5 magnitudes. This object was first reported by H. Bond as a possible optical counterpart of GRB970508 (IAUC6654) but was independently found in our data only about 0.5 day later. Log of observations of GRB970508 remnant in SAO RAS during the first 5 days after the burst are given in Table 1. Total exposures in seconds are given.

Table 1: **Log of observations of GRB970508 remnant in May.**

night, May	day, UT	telescope	B	V	R_c	I_c
09/10	09.75	1-m			300	
-"-	09.85	-"-			600	
10/11	10.77	6-m	300	200	100	300
-"-	10.93	-"-	300	200	100	300
11/12	11.76	-"-	450	300	150	450
12/13	12.87	-"-	450	600	150	900
13/14	13.88	-"-	1200	600	450	450

PHOTOMETRY

Observations were carried out with filters closely matching the BVR_cI_c Johnson-Kron-Cousins system.

The data were processed using the ESO-MIDAS software. Standard data reduction includes subtraction of the bias, flat-fielding and removing of cosmic particle traces.

Photometric conditions remained stable during two nights of May 13/14 and May 21/22.

Four bright stars (Fig. 2) in the GRB970508 field were used as secondary photometric standards. Magnitudes of these stars were determined on May 13/14 night with good photometric conditions using four standard stars in the field of PG1657+078 (Landolt, 1992). Zero-point errors are better than 0.05^m. Coordinates and magnitudes of secondary photometric standards are given in Table 3. Our R_c magnitudes of stars 2, 3, 4 are 0.20 ± 0.01 higher than the magnitudes measured by Schaefer et al. (1997).

RESULTS

Johnson-Kron-Cousins magnitudes with its errors for GRB970508 optical counterpart are given in Table 2.

1) In the period of May $\sim$9.13 UT (Castro-Tirado et al., 1997; Djorgovski et al., 1997) to May 9.85 UT the R_c brightness of the object seems to remain constant.

2) Object brightness in R_c band from May 9.85 UT to May 10.76 UT increased 1.5 magnitudes. The magnitude increase rate using ours 1-m data and the data from Palomar (Djorgovski et al., 1997) amount to 0.12 magnitude per hour.

3) The brightness maximum was $t_{max} \approx 1.5$ day after the burst. On May 10.76 UT the R_c magnitude was 19.70 and since $\approx$ May 10.76 UT a decline of brightness began.

4) Measurements of the 'broadband spectrum' on this stage (2-5 days) of fading correspond to an exponential law in all bands:

$$B = 19.689(\pm0.036) + 0.452(\pm0.014)(t - t_0)$$

$$V = 19.264(\pm0.053) + 0.449(\pm0.020)(t - t_0)$$

$$R_c = 18.874(\pm0.029) + 0.443(\pm0.011)(t - t_0)$$

$$I_c = 18.355(\pm0.050) + 0.450(\pm0.019)(t - t_0)$$

where $(t - t_0)$ is in days.

The light curve of optical counterpart during the first 5 days after the burst is shown in Figure 4.

The spectrum of the object was close to the power-law and its slope $F_\nu \propto \nu^{-1.2}$ did not change in time.

$$(B - V) = 0.43, \quad (V - R_c) = 0.39, \quad (R_c - I_c) = 0.52$$

The account for the galactic absorption $E(B-V) = 0.03$ gives $\boxed{F_\nu \propto \nu^{-1.1}}$ and the following color indeces:

$$(B - V)_0 = 0.40, \quad (V - R_c)_0 = 0.37, \quad (R_c - I_c)_0 = 0.50$$

$5)$ The observations of the object on May 22.00 UT I Jun 09.60 UT have shown that after 5 days the exponential law of brightness fading is changed to a power-law $\boxed{F_t \propto t^{-1.2}}$. Figure 5 shows the light curve.

CONCLUSIONS

The data obtained with the 1-m and 6-m telescopes SAO RAS allows to divide the brightness change curve into three stages:

1. the increase of brightness on the scale of about one day;

2. the exponential brightness fall during about 4 days with the conservation of broadband power-law spectrum;

3. the further slowing down of the brightness fading according to a power-law.

Results of photometry of GRB970508 optical remnant in SAO RAS

UT	$t - t_0$	B	σB	V	σV	R_c	σR_c	I_c	σI_c	$B - V$	$V - R_c$	$R_c - I_c$
May												
9.745	0.841					21.19	0.25					
9.848	0.944					21.13	0.18					
10.77	1.866	20.50	0.03	20.06	0.03	19.70	0.03	19.19	0.04	0.44	0.36	0.52
10.93	2.026	20.60	0.03	20.22	0.03	19.80	0.03	19.30	0.03	0.38	0.42	0.50
11.76	2.856	21.03	0.04	20.52	0.03	20.10	0.03	19.58	0.04	0.51	0.43	0.52
12.87	3.966	21.48	0.06	21.10	0.04	20.63	0.05	20.19	0.06	0.38	0.47	0.45
13.88	4.976	21.92	0.07	21.47	0.05	21.09	0.07	20.58	0.09	0.45	0.38	0.51
22.00	13.096					22.20	0.15					
Jun.												
9.60	31.696					23.28	0.10					

REFERENCES

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Castro-Tirado A. J. et al., IAU Circ No. 6657 (1997).

Costa E. et al., IAU Circ No. 6649 (1997).

Djorgovski S. et al., Nature, Vol. 387, 876 (1997).

Landolt A. U., Astron. J., 104, 340 (1992).

Metzger M. R. et al., IAU Circ No. 6676 (1997).

Mignoli M et al., IAU Circ No. 6661 (1997).

Fruchter A. et al., IAU Circ No. 6674 (1997).

Schaefer B et al., IAU Circ No. 6658 (1997).

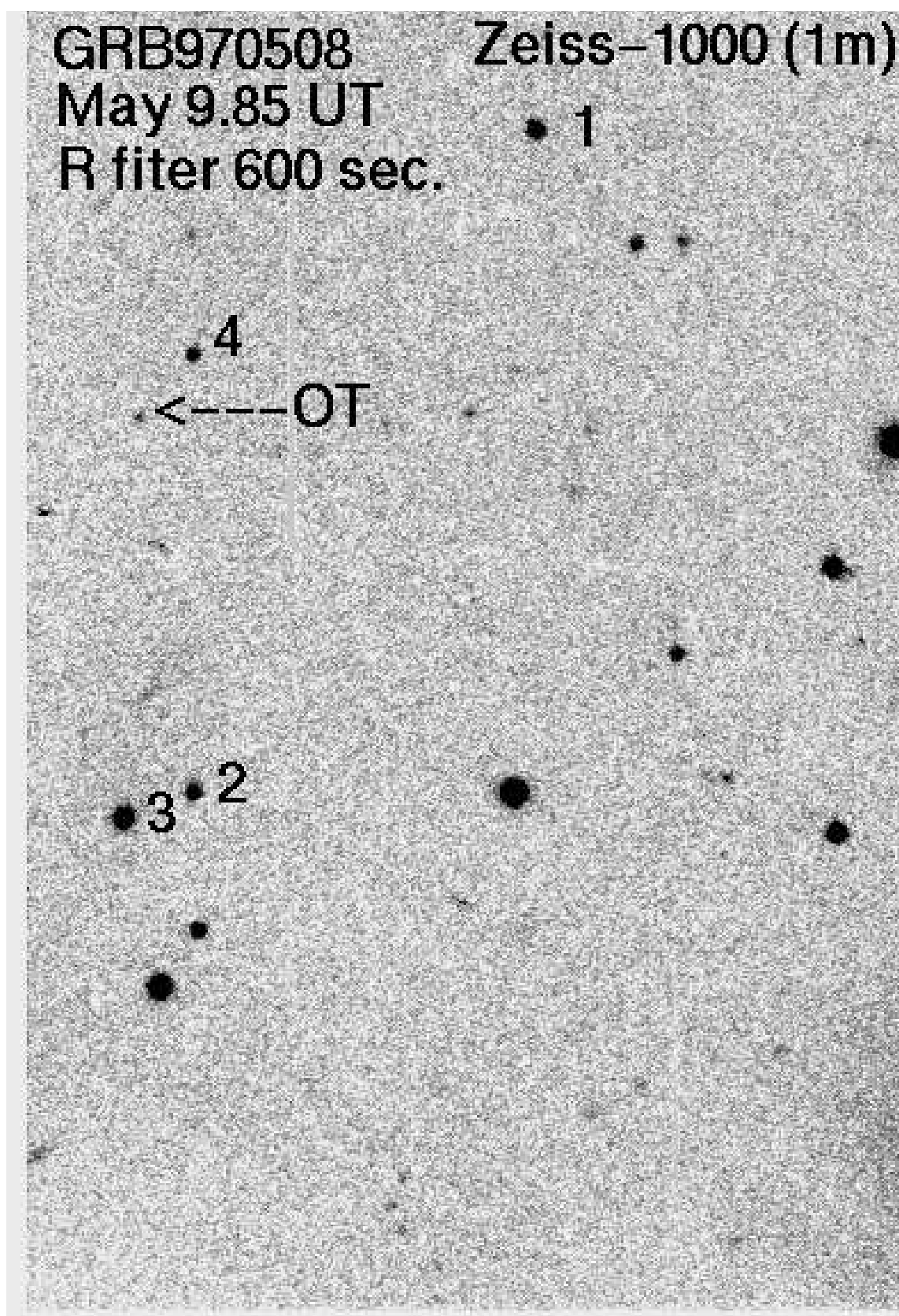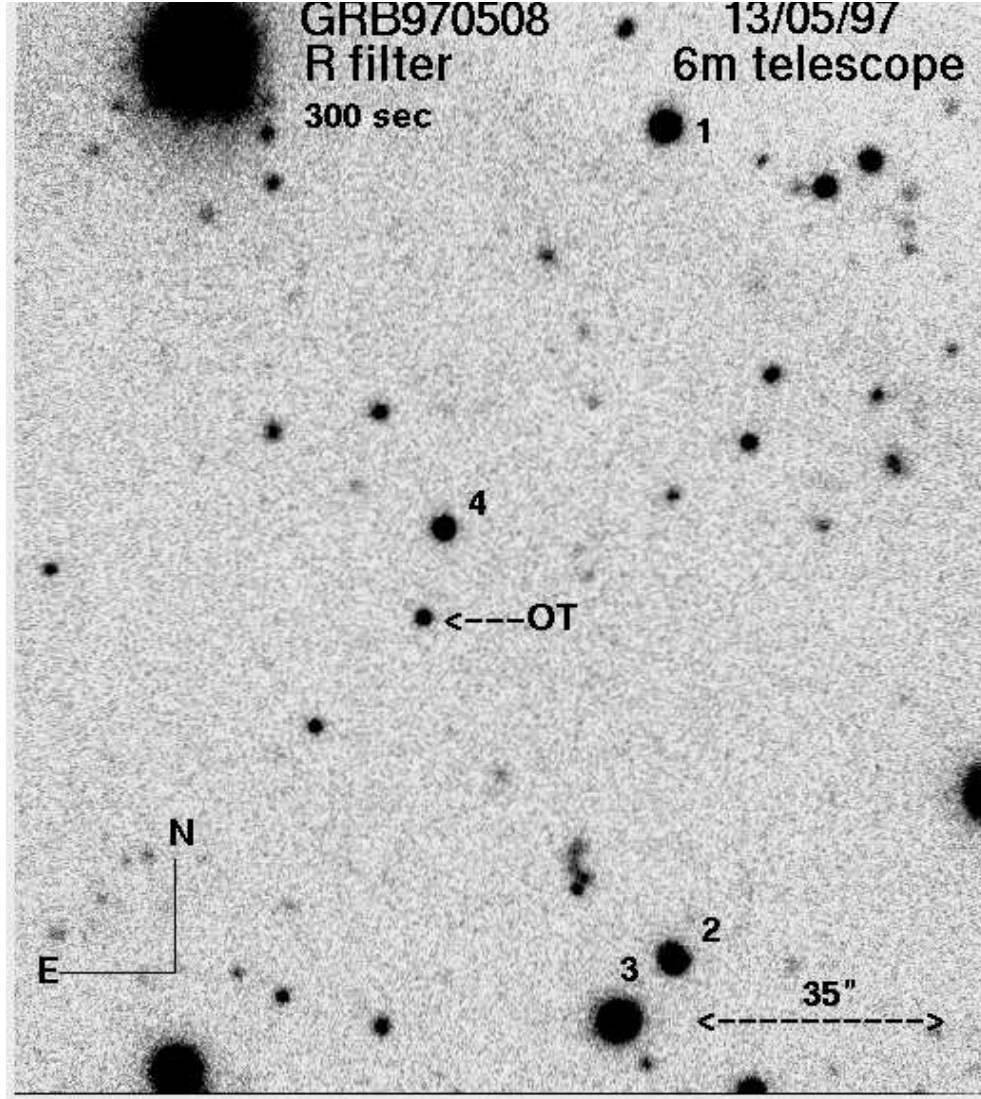Figure 1: **Field of GRB970508 optical counterpart from the 1-m telescope (Zeiss-1000).**

Figure 2: **Field of GRB970508 optical counterpart from the 6-m telescope.**

Table 2: **Coordinates and magnitudes of secondary standard stars.**

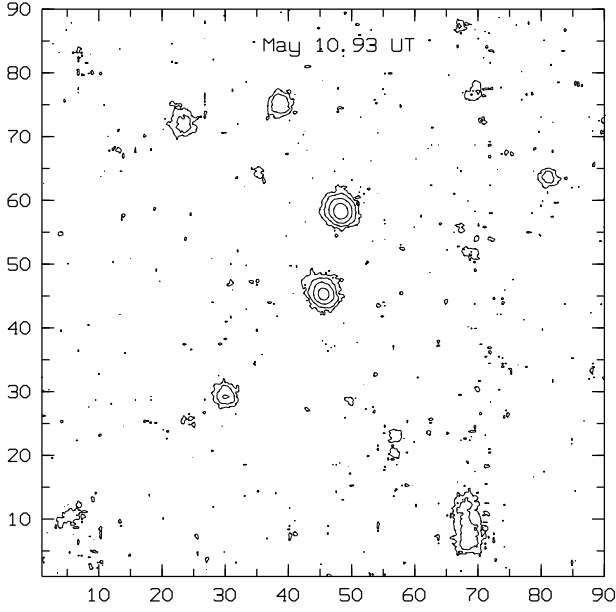| NN	$\alpha_{2000.0}$	$\delta_{2000.00}$	B	V	R_c	I_c
1	06:53:37.19	79:17:30.7	20.44	19.14	18.31	17.53
2	06:53:36.30	79:15:30.0	19.93	19.17	18.71	18.27
3	06:53:39.23	79:15:21.1	17.94	17.40	17.06	16.71
4	06:53:48.50	79:16:32.7	21.93	20.43	19.49	18.53
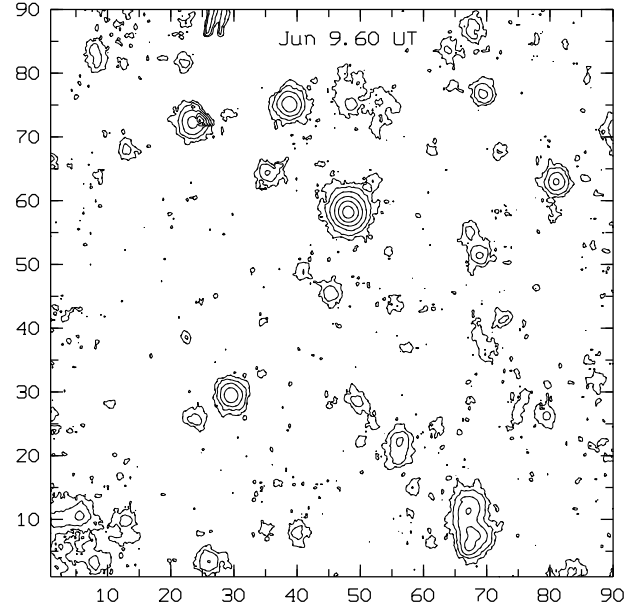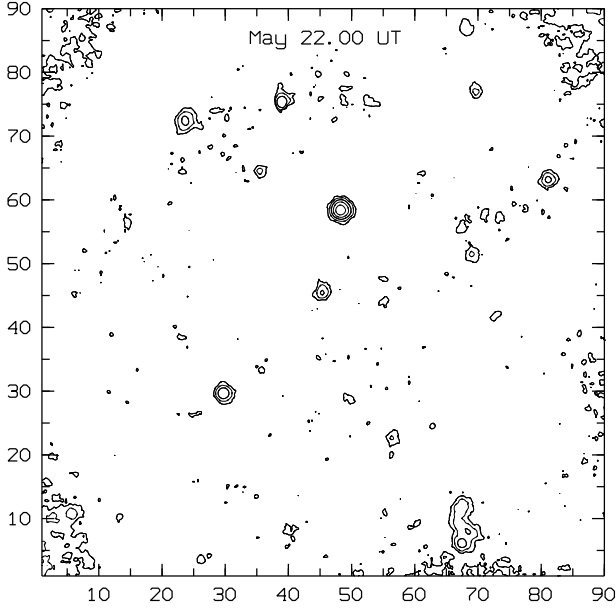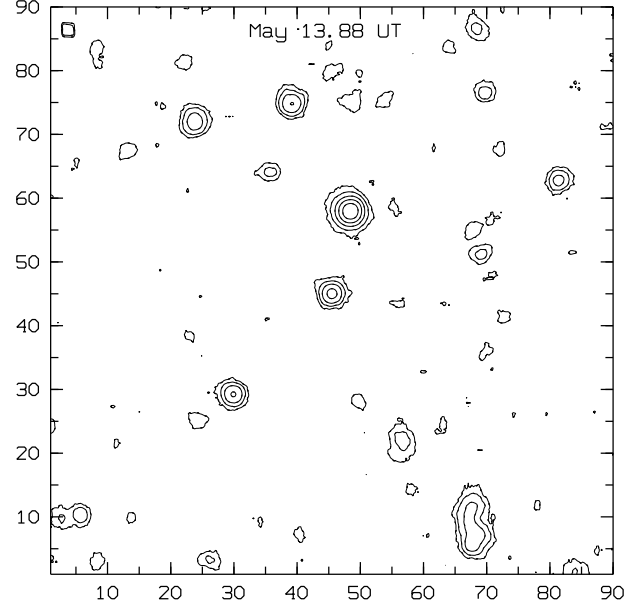
Figure 3: **Contour plots of the optical counterpart vicinity in $\mathbf{R_c}$ obtained on May 10.93 UT (100s), May 13.88 (450s), May 22.00 (1300s) and June 09.60 (4000s). The size of each fragment is $90'' \times 90''$. Optical counterpart of GRB970508 is in the center of each frame. The lowest level corresponds to $0.75 F_{sky}^{\frac{1}{2}}$, where F_{sky} is a sky flux per one pixel. Next contours are factors 2.5 apart.**
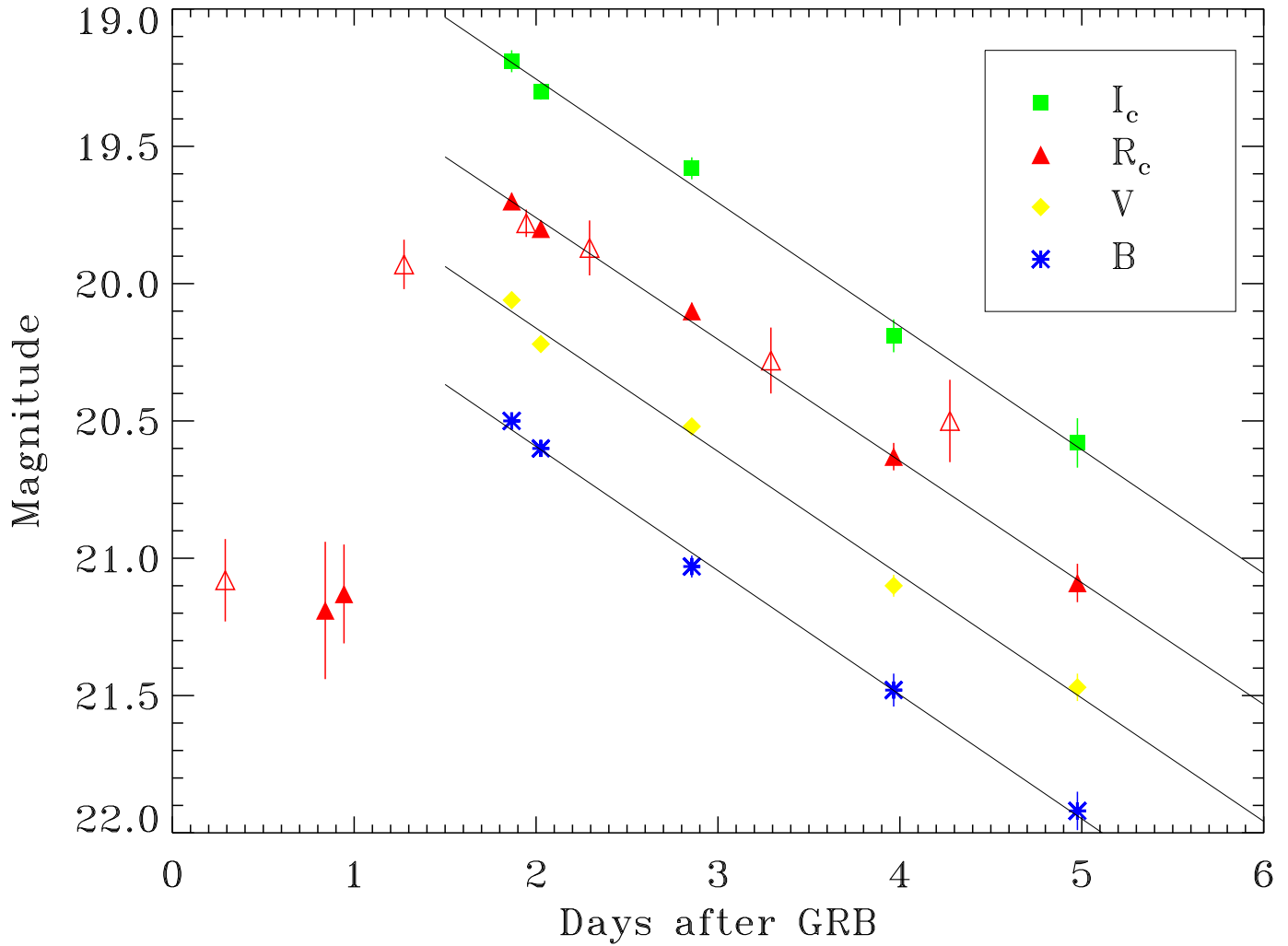
Figure 4: **The light curves of GRB970508 optical counterpart during 5 days after the burst. SAO RAS (filled symbols), and Loiano (Mignoli M. et al., 1997) ($t - t_0 = 1.95$) and Palomar (Djorgovski et al., 1997) (transformed to $R_c = r - 0.34 + A_r$) (open triangles) magnitudes with their errors are shown. Lines correspond to the equations of exponential decline of brightness reported in the text.**
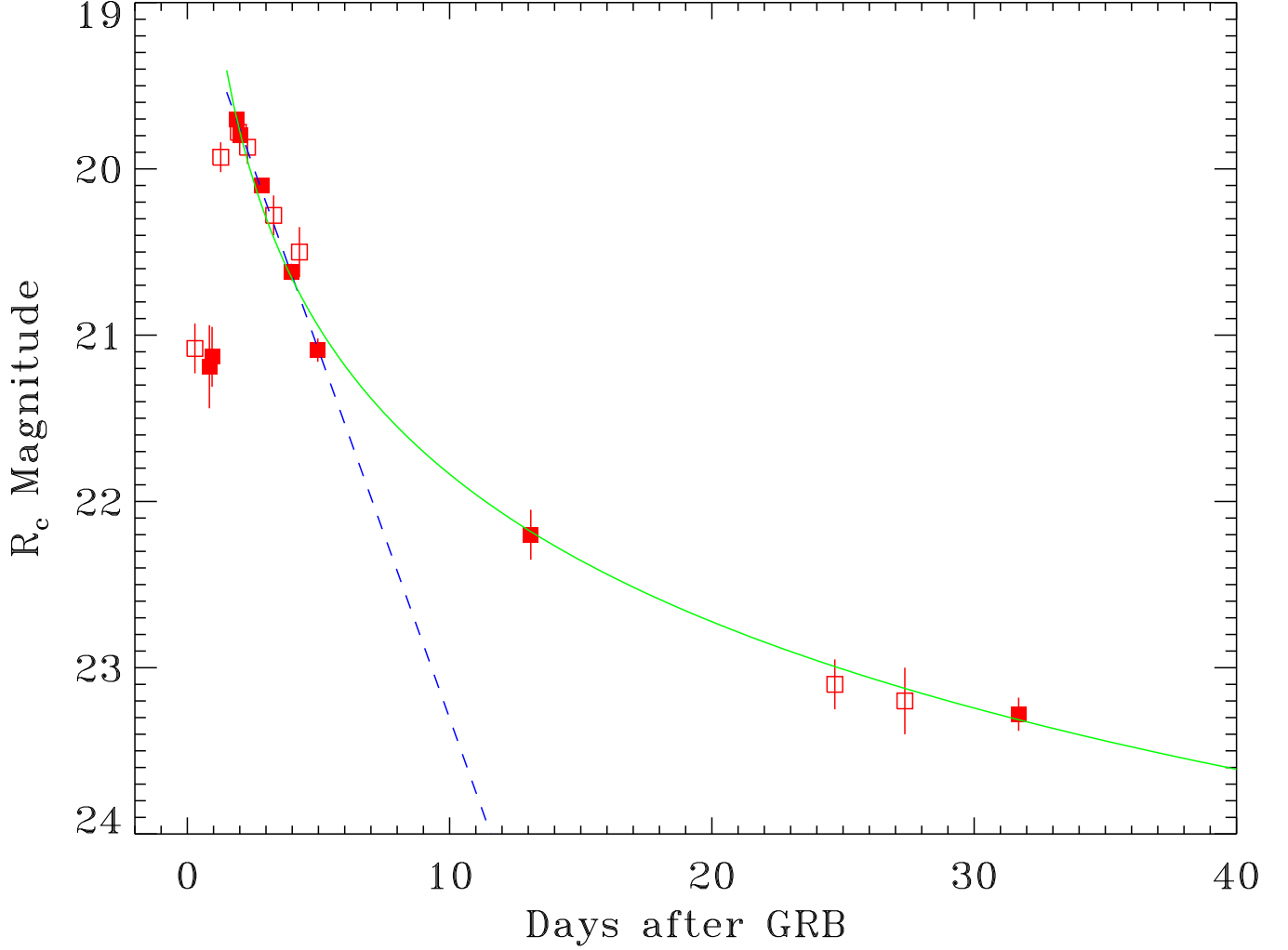
Figure 5: **R_c light curve of the optical counterpart of GRB970508 during 40 days after the burst. SAO RAS (filled squares) and Palomar (Djorgovski et al., 1997) (transformed to $R_c = r - 0.34 + A_r$), HST (Fruchter et al., 1997), Keck II (Metzger et al., 1997) (open squares) (transformed from Schaefer's photometric system to ours) magnitudes are shown. Lines corresponds to exponential law and power law for fading brightness.**

UP-DATE!

R_c light curve of <u>GRB970508</u> optical remnant up to 85 day after the burst
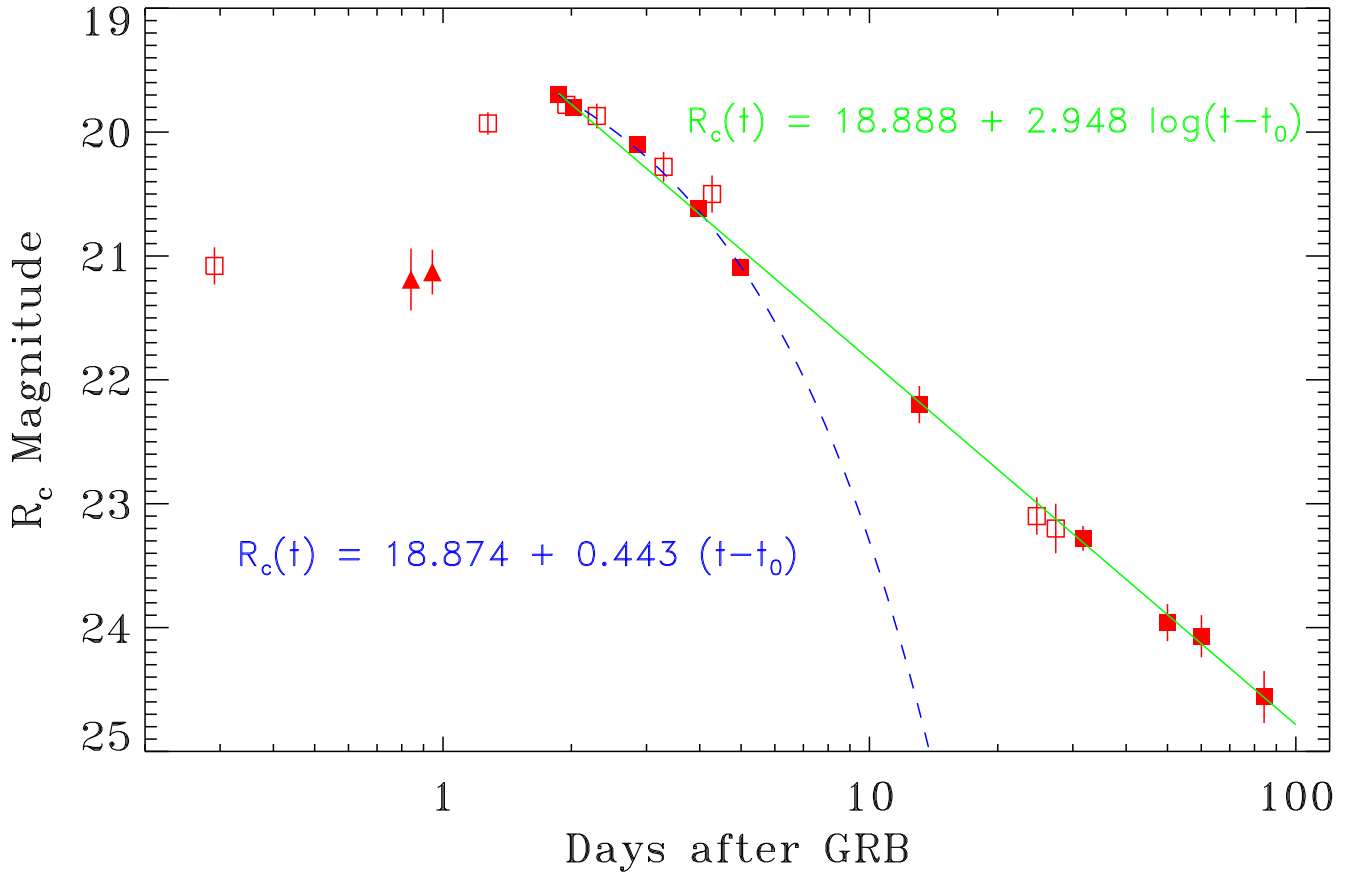
SAO RAS (including the new data obtained in June, July and August, filled squares), Palomar (Djorgovski et al., 1997), Loiano (Mignoli et al., 1997), HST (Fruchter et al., 1997), Keck II (Metzger et al., 1997) (open squares) (transformed from Schaefer's photometric system to ours) magnitudes are shown. Dashed line (using only 6-m telescope data) corresponds to exponential law for fading brightness (1) up to $t - t_o = 4.976$. Solid line (using only 6-m telescope data) corresponds to power law for fading brightness (2) up to $t - t_o = 84.246$.

1) Exponential law:

$$\mathbf{R_c = 18.874(\pm 0.029) + 0.443(\pm 0.011)\ (t - t_o)}$$

2) Power law:

$$\mathbf{R_c = 18.888(\pm 0.078) + 2.948(\pm 0.040)\ \log(t - t_o)}$$

$$\boxed{\mathbf{\alpha = 1.179\ (\pm 0.016)}}$$